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A new genus and two new species of galling aphids (Hemiptera: Aphididae) from *Distylium* (Hamamelidaceae) in Taiwan

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Abstract

Cecidological and taxonomic investigations of members of the aphid tribe Nipponaphidini (Aphididae: Hormaphidinae) are proceeding very slowly owing to the rarity of galls and difficulty in distinguishing morphologies. We describe here two new Nipponaphidini species that induce galls on the primary host, *Distylium racemosum* Siebold & Zucc. (Isu tree, Hamamelidaceae), from Taiwan. One is designated *Monzenia minuta* sp. n. which induces a closed spherical gall on twigs of *D. racemosum*. The other one is designated as a new genus, *Tripartita* gen. n., and new species, *formosana* sp. n. which can induce open, spindle-like galls on leaves of *D. racemosum* and also on leaves of *Distyliopsis dunnii* (J.H.Hemsl.) Endress (Hamamelidaceae). This is the first report of the same hormaphidine aphid species inducing galls on two distinct primary hosts. Here we provide morphological diagnoses and cecidological information for both new species.

Key words: Hormaphidinae, Nipponaphidini, *Distyliopsis*, cecidology, *Monzenia*

Introduction

Aphids are well known for their complex life cycles with host alternation, and are fastidious about their host plants, especially primary hosts. Members of subfamily Hormaphidinae have distinct tribal primary host associations, e.g., Nipponaphidini on *Distylium* (Hamamelidaceae), Hormaphidini on *Hamamelis* (Hamamelidaceae), and Cerataphidini on *Styrax* (Styracaceae) (Aoki and Kurosu, 2010; Chen and Qiao, 2012; Aoki *et al.*, 2015). Galls on primary hosts exhibit a wide range of shapes, sizes, and structural peculiarities (Ghosh, 1981; Blackman and Eastop, 1994, 2017; Aoki and Kurosu, 2010; Chen and Qiao, 2012). Several genera of nipponaphidine aphids are known to alternate between *Distylium* spp. (their primary hosts) and Fagaceae, Moraceae, and Lauraceae (their secondary hosts), but the genera, *Dinipponaphis*, *Monzenia*, and *Distylaphis*, are monoecious on *Distylium* (Blackman and Eastop, 1994, 2006, 2017). Some investigations have provided molecular and other evidence for reconstructing the phylogenetic relationships of Hormaphidinae, and the monophyly of Nipponaphidini is supported (Huang *et al.*, 2012; Chen *et al.*, 2014). Others have brought about taxonomical and cecidological knowledge of nipponaphidine aphids (Monzen, 1929, 1934, 1954; Takahashi, 1962; Sorin, 1987; Noordam, 1991; Kurosu *et al.*, 1995; Aoki *et al.*, 1999, 2015; Fukatsu *et al.*, 2005). However there have been fewer cecidological studies of the galls on nipponaphidine aphids than of those of the other two hormaphidinae tribes (Chen *et al.*, 2014).

In recent years, we extensively collected galls on *Distylium racemosum* and its relatives in Taiwan. We found that there were two new peculiar nipponaphidine aphid species included in these collections. One species is designated *Monzenia minuta* sp. n.; it induces a closed spherical gall on twigs of *D. racemosum*. The taxonomic position of the other species was unclear, because of its paradoxical features: the aphid is similar to *Hormaphis* species in morphology, but induces galls on *Distylium* and not on *Hamamelis* trees as *Hormaphis* species do (Blackman and Eastop, 1994, 2006, 2017). Finally, we decided to create a new genus, *Tripartita* gen. n. (named after the remarkable features of three-segmented antennae of the alate viviparous adult), to accept the new species,

T. formosana sp. n. *Tripartita formosana* sp. n. induces open, spindle-shaped galls on leaves of *D. racemosum* and also on leaves of *Distyliopsis dunnii* (Hamamelidaceae), which is allied to the genus *Distylium*. This is the first report of a single nipponaphidine aphid species inducing galls on two distinct primary hosts, or on trees of other than the genus *Distylium*. This paper provides morphological diagnoses and cecidological information of *M. minuta* sp. n. and *T. formosana* sp. n.

Materials and methods

Twigs and leaves of host plants that contained galls were brought back to the laboratory and photographed. Galls were severed, and aphids were deposited into 95% ethanol. Specimens were processed with carboxylene for 2–3 min to dissolve the surface wax, and then washed in 75% ethanol. Specimens were transferred to Essig's aphid fluid (75% lactic acid, 14% acetic acid, 7% phenol, and 4% distilled water) at 45–50 °C until the bodies were translucent, and finally mounted in Euparal.

Specimens were examined and photographed under an Olympus BH-2 microscope (2–40x; Tokyo, Japan). Images were prepared using Automontage (vers. 4.03) with an Olympus CAMEDIA C-7070 wide-zoom digital compact camera.

The classification scheme in this research followed Remaudière and Remaudière (1997). Representative specimens of each species are deposited in the Natural History Museum (BMNH), London, UK; Taiwan Agricultural Research Institute Insect Collection (TARIIC), Taichung, Taiwan; National Museum of Natural Science (NMNS), Taichung, Taiwan; National Taiwan University (NTU), Taipei, Taiwan.

Morphological descriptions

Genus *Monzenia* Takahashi, 1962

Type species: *Monzenia globuli* (Monzen, 1934): Takahashi, 1962: 2.

Generic diagnosis of the alate viviparous adult. Descriptions of the genus are based on the morphology of alate viviparous adults in the gall generation, and are added to Takahashi's description (Takahashi, 1962). Body oblong, rather small to medium in size. Antennae 5-segmented, segment III a little broadened near basal part. Wings almost hyaline, broad, stigma lanceolate; media vein on forewings once-branched or unbranched, anal vein as thick as cubitus; cubitus and anal vein united together into long common vein at base, Cu_{1b} thicker than Cu_{1a} . Hind wings usually with only one oblique vein, but sometimes media weakly developed. Tibiae imbricate, with distinct spinules; tarsi with some spinules, 1st tarsi with 3-3-2 or 3-3-3 setae. Siphunculi small, mere rings, nearly as large as or slightly larger than spiracular plates. Cauda rounded or with a medial process. Anal plate bilobed.

Monzenia minuta Yeh sp. n.

(Fig. 1, 2)

Apterous viviparous adult. (Description is based on 12 specimens). (Fig. 1B–D; Fig. 2A, 2B). Body oval, cuticle soft, 0.72–0.9 mm long. Head with 8–12 minute setae, without horns or dagger-like setae. Antennae 5-segmented, 100–148 μ m long; last segment with 1 circular sensorium and 4 terminal setae. Eyes with 3 facets. Ultimate rostral segment pointed, about 1.20 (1.04–1.27)-times length of 2nd segment of hind tarsus. Foreleg with 1 capitate and 2 fine long setae on dorsum of 2nd tarsal segment; mid- and hindlegs each with 2 capitate and 2 fine long setae on dorsum of 2nd tarsal segment. Abdominal tergites I–V with 4–9 minute setae; abdominal tergite VIII lightly sclerotized, with 7 or 8 setae arranged in a row; abdominal tergites II–V each with a pair of spiracles which on small sclerotic plates. Siphunculi ring-like, slightly larger than spiracular plates. Cauda and anal plate not well demarcated from each other.

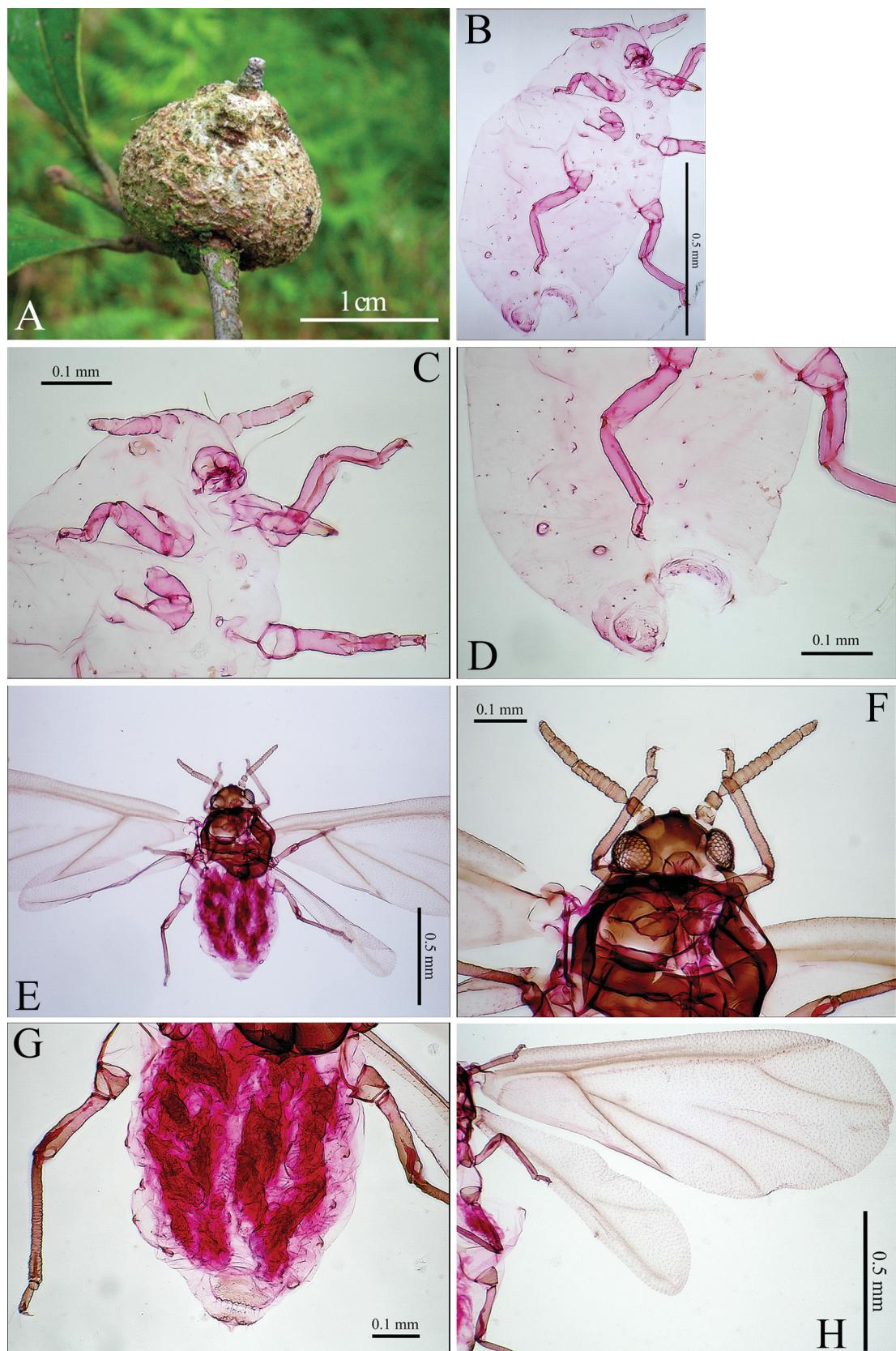


FIGURE 1. *Monzenia minuta* sp. n. (A) induces closed spherical galls on twigs of *Distylium racemosum*; (B) body, (C) head, and (D) abdomen of an apterous adult; (E) body, (F) head, (G) abdomen, and (H) wings of an alate adult.

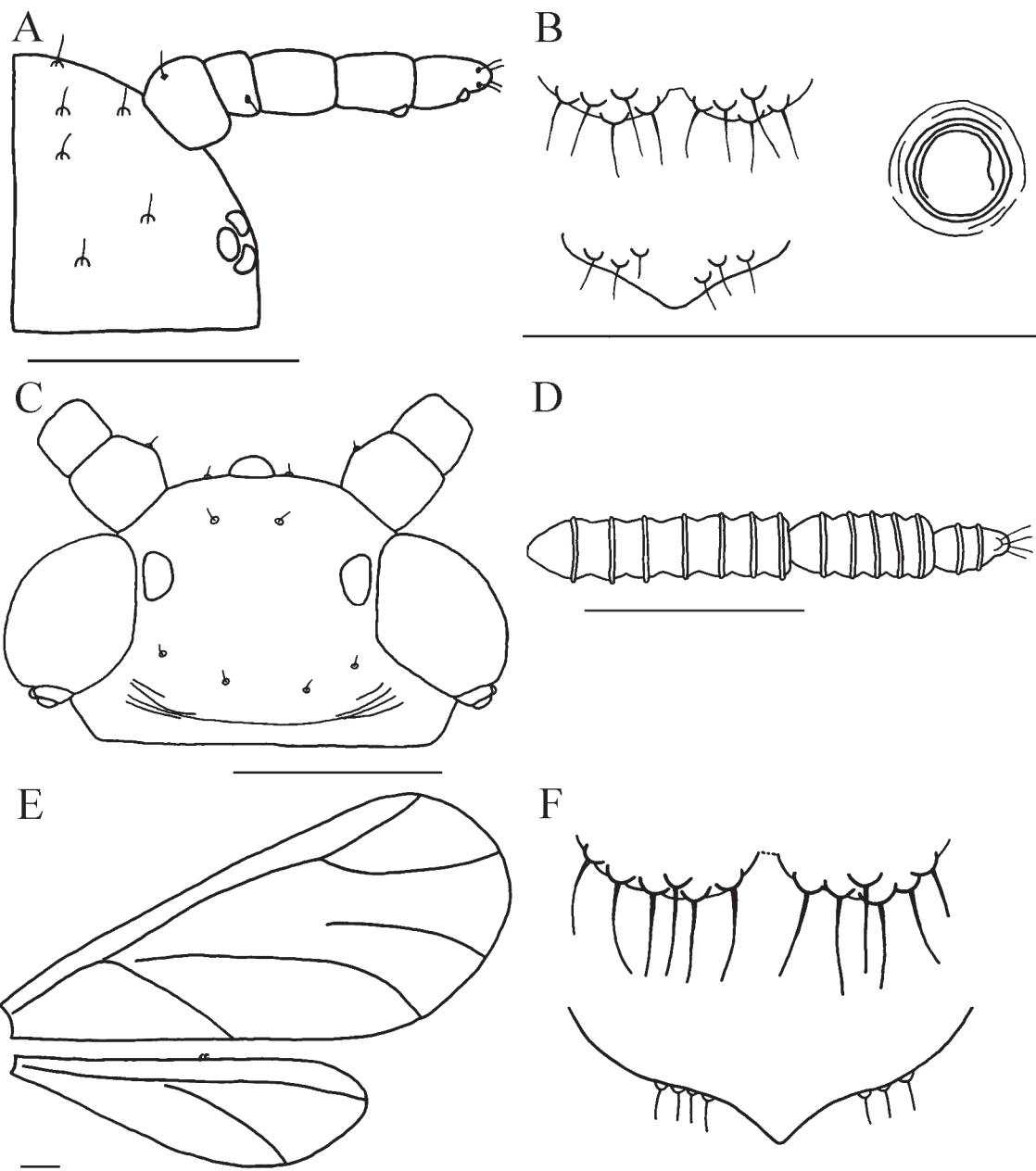


FIGURE 2. *Monzenia minuta* sp. n. (A) Head, (B) anal plate (left-upper), cauda (left-bottom) and siphunculi (right) of an apterous adult. (C) Head+antennae segments I, II, (D) antennae segments III–V, (E) wings, (F) anal plate (upper) and cauda (bottom) of an alate adult (Scale bar=0.1 mm.)

Alate viviparous adult. (Description is based on 27 specimens). (Fig. 1E–H; Fig. 2C–F). Descriptions are based on the morphology of alate viviparous adults in the gall generation. Body length about 1.01–1.20 mm. Head width (distance between 2 apices of ocular tubercles) 0.25–0.26 mm. Antennae 5-segmented, segment III about 125–140 μ m long, segment IV 60–75 μ m, segment V 35–40 μ m, total length of antennae about 1.19 (1.15–1.24)-times width of head; segment III a little broadened near basal part, with 7–9 annular secondary sensoria except on basal 1/5 or 1/7, which gradually narrows to a constricted base; segment IV with 4–6 annular secondary sensoria; segment V with 1 small circular sensorium and 4 terminal setae, with 2 or 3 annular secondary sensoria. Wings almost hyaline, broad, stigma lanceolate; media vein unbranched on forewings. Tibiae imbricate, with distinct spinules; tarsi with some spinules, 1st tarsal segments with 3-3-3 setae, 2nd tarsal segments with 3-4-4 capitate distal setae. Abdominal tergites II–V each with a pair of spiracles which on small sclerotic plates. Siphunculi slightly elevated, ring-like, slightly larger than spiracular plates. Cauda with a medial process, with many spinules at base. Anal plate bilobed, with 4–6 setae on each lobe.

Material examined. **Holotype**, one alate viviparous adult & one apterous viviparous adult, Yuanshan Township, Ilan Co., Taiwan, on *D. racemosum*, 23-ix-2006, H. T. Yeh (#505). (The individuals of holotype are marked by circles on the slide.)

Holotype-specimen deposition: NTU, Taipei, Taiwan.

Paratype, 27 alate viviparous adults & 12 apterous viviparous adults (on 7 microscope slides), Yuanshan Township, Ilan Co., Taiwan, on *D. racemosum*, 23-ix-2006, H. T. Yeh (#505)(BMNH, NMNS, NTU, TARIIC). 4 alate viviparous adults, Yuanshan Township, Ilan Co., Taiwan, on *D. racemosum*, 26-ix-2009, G. S. Tung (#701)(NTU).

Etymology. The species epithet is a Latin word, ‘*minuta*’, meaning minute or small, emphasizing the small body size of the alate viviparous adult.

Remarks. This species induces closed spherical galls on twigs of *D. racemosum* (Fig. 1A). The morphologies of alate viviparous adults of *M. minuta* sp. n. can be distinguished from those of *M. globuli* (Monzen) and *M. ihai* Sorin as follows:

Characters*	<i>M. minuta</i> sp. n.	<i>M. globuli</i>	<i>M. ihai</i>
body size (mm)	1.01–1.20	1.60–2.00	1.78
ratio of lengths of antennal segments III–V to head width	1.19 (1.15–1.24)	1.60–1.70	1.70
numbers of antennal secondary rhinaria on III, IV, and V	7–9, 4–6, and 2 or 3	18–23, 9–12, and 6–10	21–28, 10–15, and 9–12
media vein on forewings	unbranched	once-branched	once-branched

* Based on the original descriptions by Monzen (1934) for *M. globuli* and by Sorin (1996) for *M. ihai*.

Genus *Tripartita* Yeh gen. n.

Type species: *Tripartita formosana* Yeh sp. n.

Generic diagnosis of the alate viviparous adult. Description of the genus is based on the morphology of alate viviparous adults in the gall generation. Body medium to large in size (1.53–2.34 mm). Antennae long, more than half of body length, 3-segmented; segment III often thickened on basal 1/3–1/2, with densely annular secondary sensoria. Rostrum short, not reaching coxae of mid-leg; rostral segments IV+V blunt. Prothorax well-developed and prominent, with 2 groups of wax glands on tergite. Tibiae imbricate, with distinct spinules; tarsi with minute imbricate spinules, 1st tarsal segments with 3-3-3 setae, 2nd tarsal segments with 4-4-4 capitate distal setae. Groups of wax glands present on abdominal segments I–VII, which are arranged in a row on each tergite; abdominal tergites I–VII covered with pale minute sculpturing which has a slightly reticulated pattern; tergites VII and VIII slightly sclerotized; 4 pairs of spiracles on each side of segments II–V. Siphunculi absent. Cauda transverse, not constricted at base. Anal plate bilobed.

Etymology. The generic name ‘*Tripartita*’ refers to the unusual three-segmented antenna of the alate viviparous adult.

Tripartita formosana Yeh sp. n.

(Figs. 3, 4, 5, 6)

Fundatrix. (Description is based on 13 specimens). (Fig. 3A–C, 5A, 5B). Body puffed out, cuticle soft, 1.38–2.50 mm long. Head without horns or dagger-like setae. Antennae 3-segmented; segment III with imbricate sculpturing, 170–215 µm long, about 1.13 (1.06–1.21)-times length of tibia of foreleg, with a circular sensorium and 5 or 6 terminal setae on tip. Eyes with 3 facets. Rostrum stout, last 3 segments 170–210 µm long; ultimate rostral segment about 1.40–1.60-times length of 2nd tarsus of hindleg. Two pairs of spiracles with large spiracular plates raised on intermediate areas between prothorax-mesothorax and mesothorax-metathorax; abdominal spiracles without sclerites nor tubercles nearby. Legs short. Siphunculi absent. Abdominal tergite VIII slightly sclerotized with

imbrications, with 5–7 setae; genital plate with 9–16 setae. Cauda transverse, not constricted at base, with 6–8 setae which are divided into 2 clusters on each side. Anal plate bilobed, with 5 or 6 setae on each lobe.

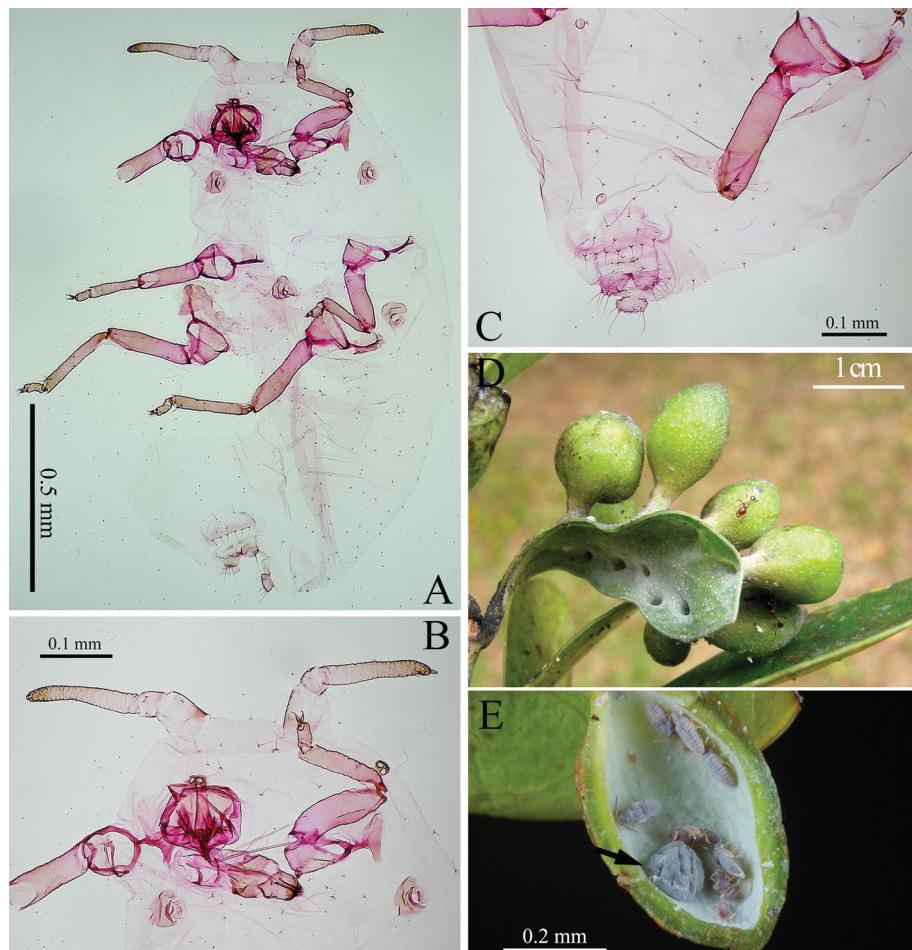


FIGURE 3. Galls and morphology of *Tripartita formosana* sp. n.; (A) body, (B) head, and (C) abdomen of a fundatrix; (D) open, spindle-like galls on leaves of host plant; (E) the arrow indicates a fundatrix inside a gall.

Alate viviparous adult. (Description is based on 34 specimens). (Fig. 4A–D, 5C–F). Body length 1.53–2.34 mm. Head width (distance between 2 apices of ocular tubercles) 0.42–0.50 mm. Antennae long, about 0.69 (0.59–0.85)-times body length and 2.83 (2.33–3.41)-times width of head, 3-segmented (some individuals obviously 4-segmented, but segments III and IV not definitely delimited), segment III usually thickened on basal 1/3–1/2, with 61–110 annular secondary sensoria, with 4–6 terminal setae. Rostrum short, not reaching coxae of mid-leg; ultimate rostral segment blunt, about 0.64 times length of 2nd tarsal segment of hindleg. Prothorax well-developed and prominent, with 2 groups of wax glands on tergite. Tibiae imbricate, with distinct spinules; tarsi with minute imbricate spinules, 1st tarsal segments with 3-3-3 setae, 2nd tarsal segments with 4-4-4 capitate distal setae. Groups of wax glands present on abdominal segments I–VII, which are arranged in a row on each tergite; abdominal tergites I–VII covered with pale minute sculpturing with a slightly reticulated pattern; tergites VII and VIII slightly sclerotized; 4 pairs of spiracles on each side of segments II–V. Siphunculi absent. Cauda transverse, not constricted at base, with 6–12 setae which are divided into 2 clusters on each side. Anal plate bilobed, with 5–11 setae each.

Material examined. **Holotype**, one alate viviparous adults, Hengchun Township, Pingtung Co., on *D. racemosum*, 29-vi-2006, H. T. Yeh (#491). One fundatrix, Hengchun Township, Pingtung Co., on *D. racemosum*, 9-x-2006, H. T. Yeh (#520). (The individuals of holotype are marked by circles on the slide.)

Holotype-specimen deposition: NTU, Taipei, Taiwan.

Paratypes, 3 alate viviparous adults, Hengchun Township, Pingtung Co., on *D. racemosum*, 29-vi-2006, H. T. Yeh (#491)(NTU). 6 alate viviparous adults (on 2 microscope slides), Hengchun Township, Pingtung Co., on *D. racemosum*, 29-vi-2006, H. T. Yeh (#493)(NTU); 6 alate viviparous adults, Hengchun Township, Pingtung Co., on *D. racemosum*, 9-ix-2006, H. T. Yeh (#501)(NTU); 6 fundatrices, Hengchun Township, Pingtung Co., on *D.*

racemosum, 9-x-2006, H. T. Yeh (#520)(NTU); 6 fundatrices, Hengchun Township, Pingtung Co., on *D. racemosum*, on 18-xi-2006, H. T. Yeh (#559)(NTU); 3 alate viviparous adults, Hengchun Township, Pingtung Co., on *D. racemosum*, 25-ii-2007, H. T. Yeh (#582)(NTU); 23 alate viviparous adults (on 7 microscope slides), Hengchun Township, Pingtung Co., on *D. racemosum*, 24-iii-2007, H. T. Yeh (#586)(BMNH, NMNS, NTU, TARIIC); 6 alate viviparous adults, Yuanshan Township, Ilan Co., on *D. racemosum*, 1-vi-2007, H. T. Yeh (#593)(NTU); 3 alate viviparous adults, Hengchun Township, Pingtung Co., on *D. racemosum*, 26-v-2007, H. T. Yeh (#607)(NTU); 3 alate viviparous adults, Hengchun Township, Pingtung Co., on *D. racemosum*, 31-v-2008, H. T. Yeh (#681)(NTU); 9 alate viviparous adults, Xitou (Lugu Township), Nantou Co., on *D. racemosum*, 20-iii-2013, H. T. Yeh (NTU); 6 alate viviparous adults, Xitou (Lugu Township), Nantou Co., on *D. racemosum*, 24-v-2013, H. T. Yeh (NTU); 12 alate viviparous adults, Hengchun Township, Pingtung Co., on *D. racemosum*, 2-iv-2017, H. T. Yeh (NTU). 7 alate viviparous adults, Yuanshan Township, Ilan Co., on *Distyliopsis dunnii*, 31-iii-2007, H. T. Yeh (#591) (NTU); 3 alate viviparous adults & 1 fundatrix, Yuanshan Township, Ilan Co., on *Distyliopsis dunnii*, 8-vii-2007, H. T. Yeh (#619)(NTU).

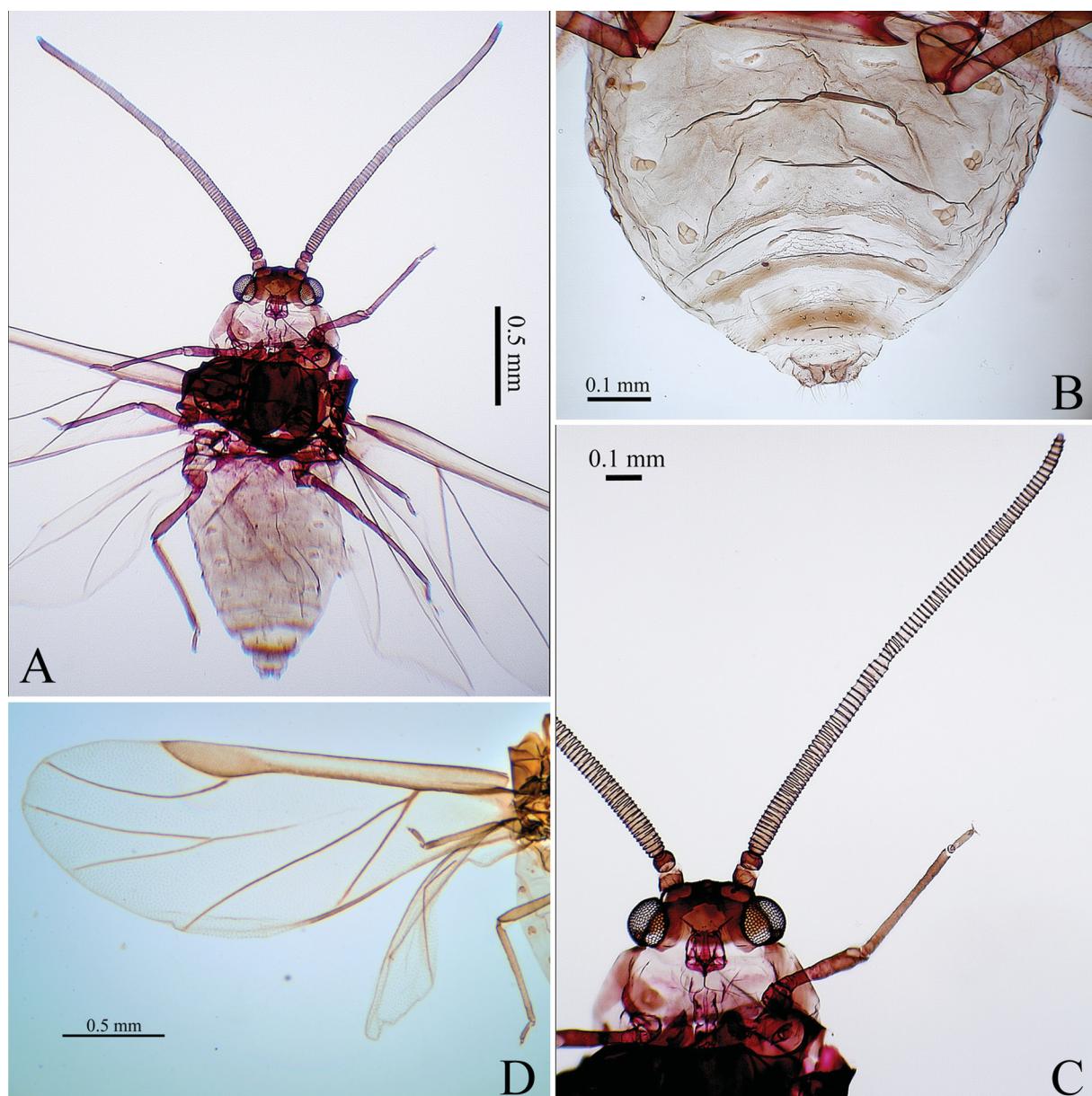


FIGURE 4. Alate adult of *Tripartita formosana* sp. n. (A) Body, (B) abdomen, (C) head, and (D) wings

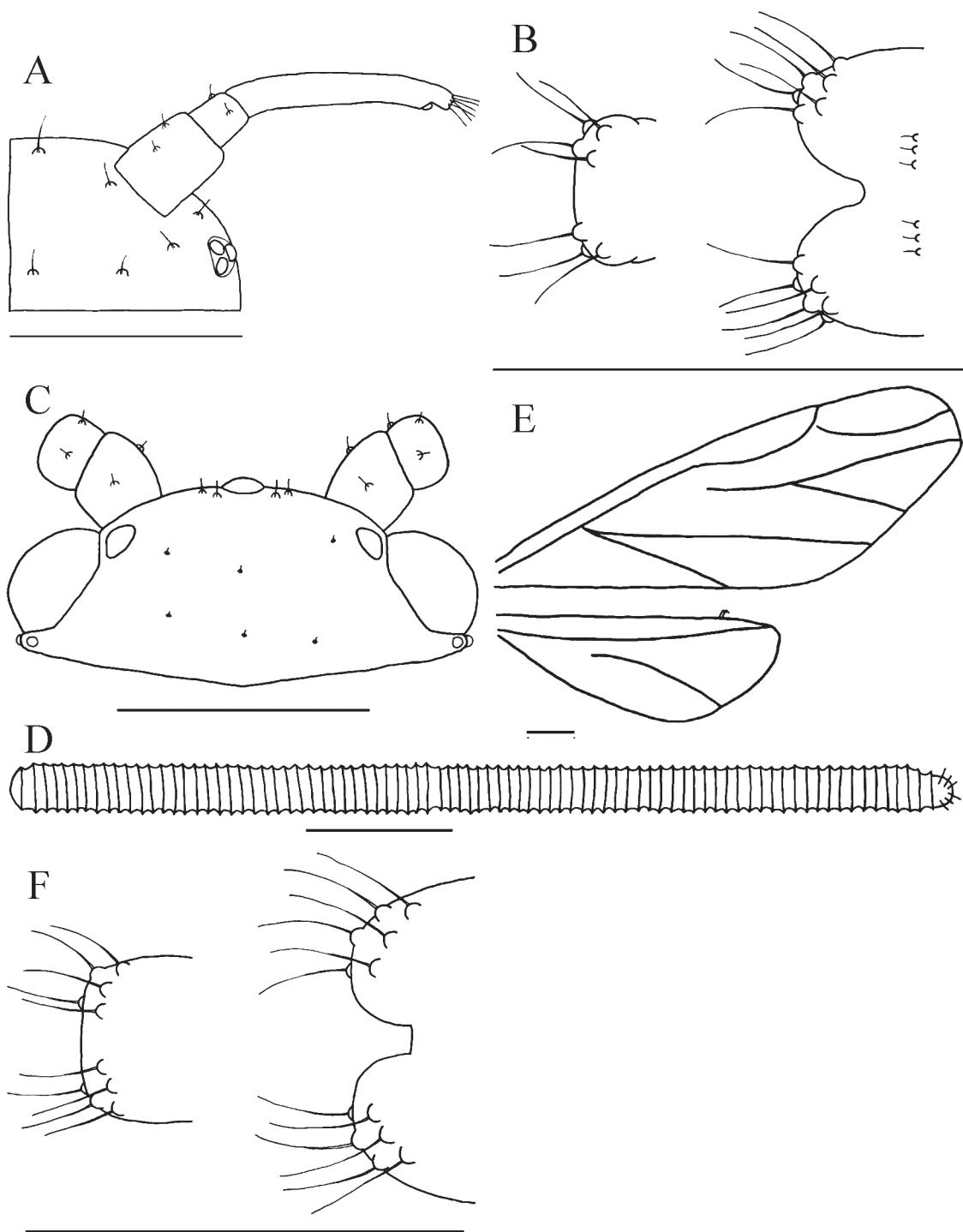


FIGURE 5. *Tripatita formosana* sp. n. (A) Head, (B) anal plate (right) and cauda (left) of a fundatrix. (C) Head+antennae segments I, II, (D) antenna segment III, (E) wings, (F) anal plate (right) and cauda (left) of an alate adult (Scale bar=0.2 mm.)

Etymology. The species name ‘*formosana*’ is derived from the first-recorded place, Taiwan (‘Formosa’ is an old toponym of Taiwan).

Remarks. Incipient galls of *T. formosana* were found in early October, and each gall contained a fundatrix. The fundatrix existed in the gall from October until the following May, and its body was gradually puffed out, ultimately exceeding 2.5 mm in length. Alate viviparous adults, offspring of the fundatrix can be found from late February to early June in the galls. After all alates emigrated from the galls, a few first-instar larvae were observed walking around on the surfaces of the galls and leaves. We consider that these first-instar larvae (Fig. 6A) to be functionally sterile soldiers. The antennae of alate viviparous adults are usually divided into three segments, with a

very long undivided flagellum (segment III). However several individuals (n=4) had one antenna that was four-segmented (Fig. 6B). Because the antennae of last instar nymphs are four-segmented (Fig. 6C), the antenna III and IV are fused together in the adult stage. For these reasons, we consider the three-segmented antennae of the alates is an apomorphic character state, which does not contradict our placement of *T. formosana* in the tribe, Nipponaphidini.

This species was first found to induce spindle-like galls on leaves of *D. racemosum*, opening on the underside of the leaf (Fig. 3D, E). Moreover, *T. formosana* was subsequently found to induce similar galls on leaves of *Distyliopsis dunnii*, which also belongs to Hamamelidaceae. The alates obtained from the two different hosts are not significantly different in morphology, and there is no doubt that the two belong to the same species. This is the first case of a single nipponaphidine species inducing galls on two primary hosts that belong to different genera. The size of mature galls on *D. racemosum* was 8.5–15.6 (average, 11.3) mm long and 4.0–8.1 (average, 5.8) mm in diameter, and that on *Distyliopsis dunnii* was 10.0–19.2 (average, 13.8) mm long and 4.2–9.4 (average, 6.5) mm in diameter. Several galls were formed on a single leaf.

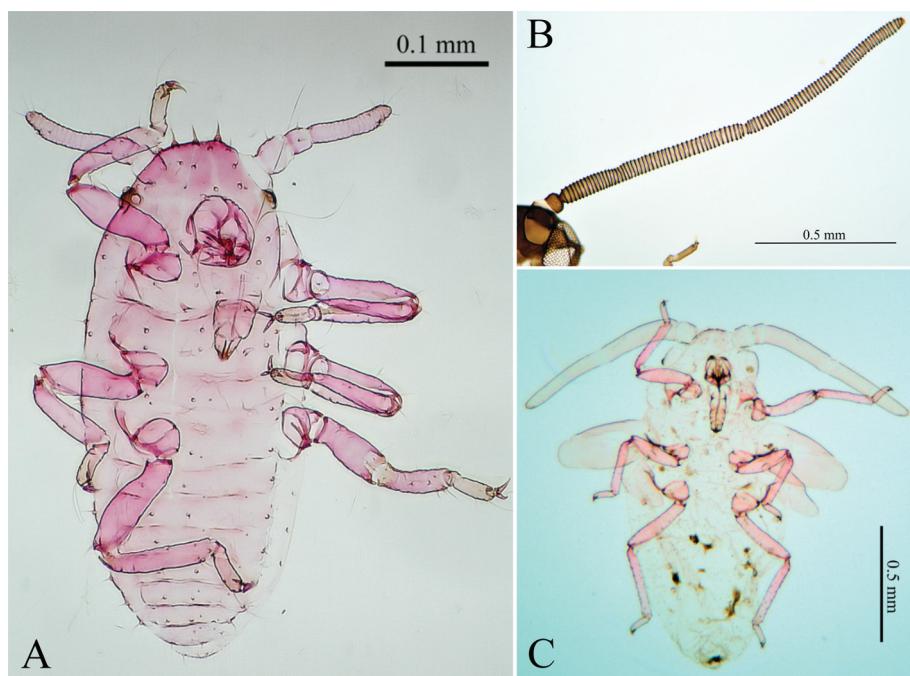


FIGURE 6. *Tripartita formosana* sp. n. (A) Presumed sterile soldier. (B) Alate adult with a 4-segmented antenna (C) Last instar nymph

Discussion

We described two new aphid species, *M. minuta* sp. n. and *T. formosana* sp. n., which induced galls on the host, *D. racemosum*; the later species also induced galls on the host, *Distyliopsis dunnii*. We postulate that the life cycle of *M. minuta* is autoecious on the primary host like congeners (Takahashi, 1962; Sorin, 1996). The gall induced by *T. formosana* is very peculiar, because no other galls on *D. racemosum* induced by Nipponaphidini species are known to be persistently open since the gall initiation. The shape of this open gall is similar to galls induced by *Hormaphis betulae* on leaves of *Hamamelis japonica* (Hamamelidaceae) (Kurosu and Aoki, 1991), but no Hormaphidini species was previously known to induce galls on *Distylium* spp. (nor on *Distyliopsis* spp.). The alate of *T. formosana* is similar to those of *Hormaphis* species in having three-segmented antennae (but antennae of *T. formosana* are much longer), but we consider these similarities are due to convergent evolution. It was difficult to determine the tribal position of *T. formosana* owing to its unusual combination of ecological and morphological characters. The taxonomic position of *T. formosana* within the tribe Nipponaphidini is still unclear. Molecular phylogenetic analyses might resolve it.

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